APPLICATIONS OF ADVANCED FINE COAL CLEANING AND DEWATERING TECHNOLOGIES

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ABSTRACT

Although several advanced technologies have been developed in recent years for cleaning fine coal, very few of these processes have become widely used in the coal preparation industry. Consequently, large amounts of coal fines are being burned directly without cleaning or are being discarded to refuse ponds. This situation represents a loss of profit and a potential environmental concern for coal and utility companies. Reasons cited for the slow deployment of cleaning technologies include the high costs of dewatering fine coal and the large financial risks associated with implementing new technologies. These barriers may be overcome through the use of novel coal dewatering technologies recently developed at the Center for Coal and Minerals Processing. Implementation of the new dewatering technologies can be justified by properly assessing the impacts of the advanced technologies on overall plant performance rather than on the financial gains attainable from the fine-coal-cleaning circuit only. In this paper, the application of several different advanced fine-coal-cleaning and dewatering technologies will be discussed, particularly in view of the large financial gains that can be achieved by optimizing the overall plant performance.

INTRODUCTION

The treatment of fine coal is the least efficient and most costly step in coal preparation. For example, consider the coal quality values given in Table 1 for a typical preparation plant operating in the eastern United States. The size-by-size analyses show that the ash content of the clean coal deteriorates from 7.5% to 10.8% with decreasing particle size. In addition, the moisture content of the fine fraction is nearly five times higher than the coarse fraction (i.e., 25.1% versus 5.1%). The high moisture content of the fines is a particular problem due to the increasingly stringent moisture constraints imposed on coal producers by utility contracts. Furthermore, field surveys conducted at Virginia Tech suggest that, on average, the cost to treat fine coal is three to four times higher than that to clean coarse coal. Consequently, it is often more practical to discard the fines, provided that this size fraction constitutes only a small portion of the product stream. A recent survey conducted by the U.S. Department of Energy indicates that U.S. coal producers currently discard between 27 and 36 million metric tons of fresh fine coal to refuse ponds each year. To date, approximately 1.8 billion metric tons of fine coal has been discarded in abandoned ponds, and 450 to 725 million tons are in active ponds. The discarded fines represent the misuse of valuable natural resources, loss of profit for coal producers, and creation of significant environmental problems.

Size (mm)	Mass (%)	Ash (%)	Moisture (%)
Plus 0.5	80.8	7.5	5.1
0.5 x 0.15	11.8	8.8	12.3
Minus 0.15	7.4	10.8	25.1
Feed	100.0	7.9	7.4

Table 1. Typical Ash and Moisture Values for Different Sizes of Clean Coal

ADVANCED FLOTATION

A number of new technologies have been developed in recent years to improve the efficiency and lower the costs of fine coal cleaning. One such technology, known as Microcel, was developed at Virginia Tech under the auspices of the U.S. Department of Energy. This technology was conceived after several years of fundamental research that showed that smaller air bubbles could enhance the rate of flotation. The essential features of this technology are shown in Figure 1. In the lower section of the column, small bubbles (called microbubbles) are generated by passing air and coal slurry through parallel in-line static mixers. The mixers are mounted outside the column to simplify inspection and replacement. The microbubbles are capable of recovering very fine coal particles (<20 microns) that are difficult to capture using larger bubbles generated in conventional flotation machines. In addition, fresh wash water is added to the top of the column froth to remove ash-forming minerals, such as clay, that may be entrained into the clean coal product. The unique combination of the microbubble generator and the froth-washing system provides a high quality froth product while maintaining a high rate of coal recovery.

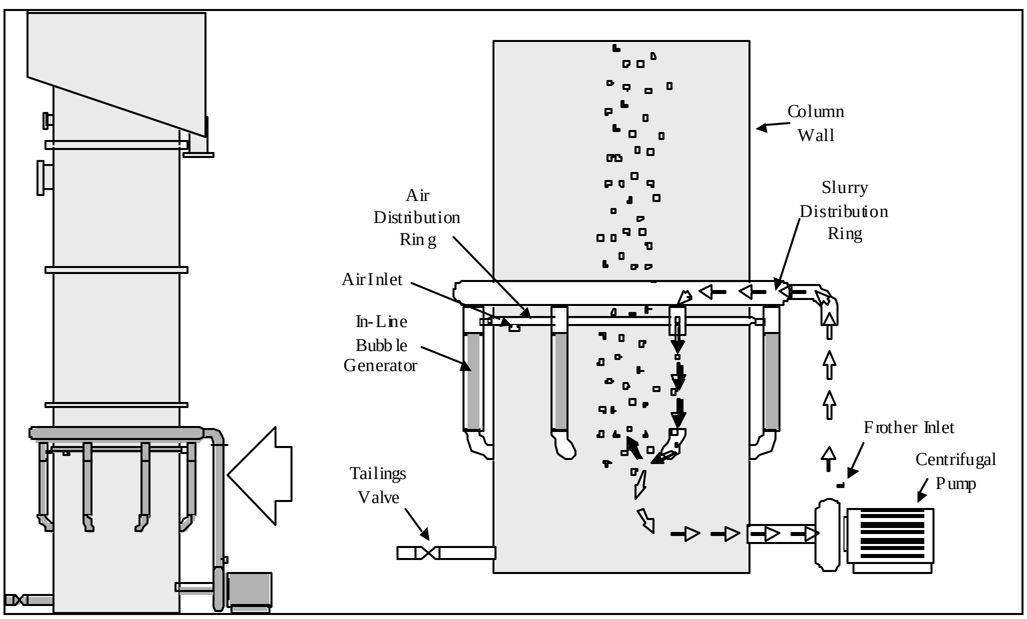

Figure 1. Schematic of the Essential Features of the Microcel Flotation Technology

Table 2 provides a listing of some of the full-scale installations of Microcel technology. The most notable of these includes the installations at the preparation plants at Middle

Fork, Peak Downs, and Brooks Run. The Middle Fork facility, which is located in southwestern Virginia, was the first multi-cell installation of the Microcel technology. Five 3-meter-diameter columns were installed at this site to recover coal fines from a 30-year-old refuse pond (see Figure 2). The columns replaced an existing bank of conventional cells that, on average, produced clean coals with ash contents as high as 15%. After installing the Microcel units, the clean coal ash was reduced to less than 8% with a corresponding increase of more than 15% in combustible recovery (Davis *et al*., 1994).

Company / Installation / Location	**Number**	**Geometry**
Zeigler Coal, Marrowbone Plant, USA	1	2.4 x 7.5 m
Pittston Coal, Middle Fork Plant, USA	5	3.0 x 7.5 m
ANR Coal, Roxanna Plant, USA	2	3.0 x 7.5 m
Cyprus-Amax, Lady Dunn Plant, USA	3	4.0 x 8.5 m
Pittston Coal, Holston Plant, USA	1	4.2 x 8.0 m
Coastal Coal, Toms Creek Plant, USA	2	4.2 x 8.0 m
Coastal Coal, Brooks Run Plant, USA	2	4.5 x 8.0 m
Ohio Coal Development, OCTAD Plant, USA	1	1.8 x 9.0 m
Chaili Plant, China	6	3.0 x 7.5 m
BHP, Peak Downs Plant, Australia	16	3.0 x 7.5 m
International Carbon, Graphite Plant, Australia	1	1.5 x 9.0 m
Kum-Am, Graphite Plant, Korea	3	1.5 x 9.0 m

Table 2. Examples of Full-Scale Installations of the Microcel Technology

The second notable installation of Microcel columns is at the Peak Downs plant near Queensland, Australia (see Figure 3). This site is believed to represent the single largest installation of coal columns anywhere in the world. At this plant, sixteen 3-meter-diameter Microcel columns were installed to replace a traditional split-feed flotation circuit. The Microcel columns reduced the ash content of the froth product from about 9.5% to 6%, which, in turn, allowed the operating gravities in the coarse circuit to be raised such that the total plant realized a 4% increase in yield (Brake and Eldrige, 1996). Finally, the largest diameter Microcel columns constructed to date were recently installed at the Brooks Run preparation plant. This facility, located in northern West Virginia, installed two 4.5-meter-diameter Microcel columns to treat coal fines of less than 0.15 mm. The twin-column circuit currently produces approximately 40–45 tons/hr of additional clean coal at a 10% ash content. Due to the economy of scale, the larger columns reduced capital costs by more than one third compared to the smaller 3-meter-diameter columns installed at the Middle Fork and Peak Downs plants.

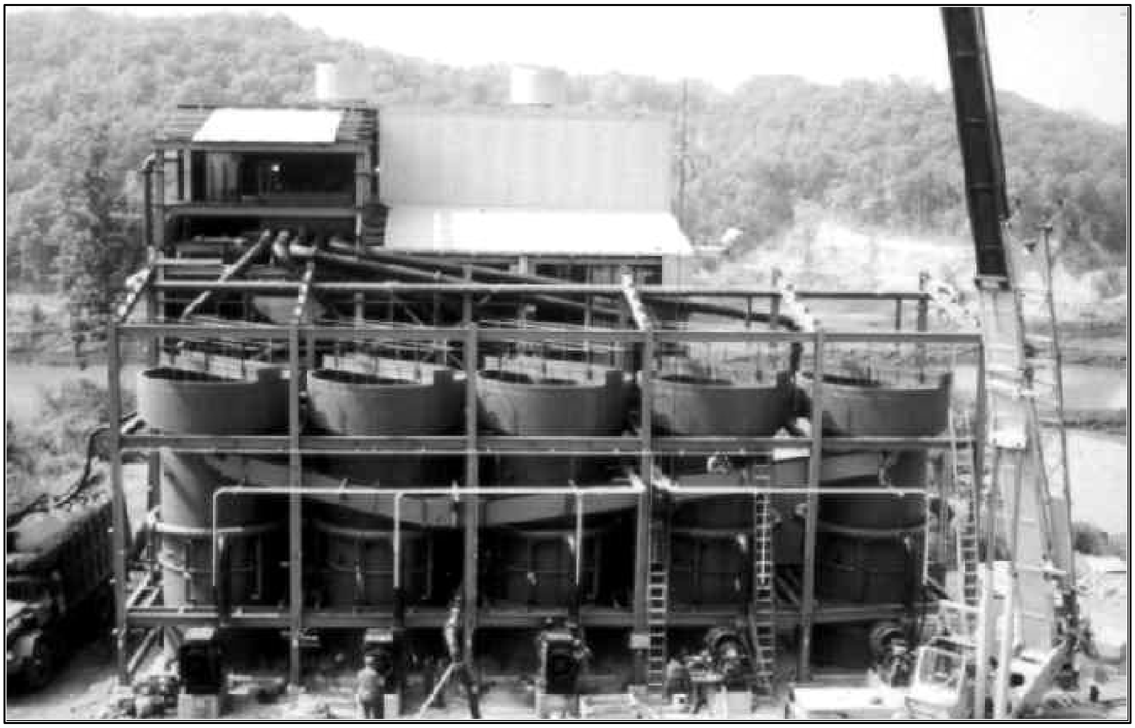

Figure 2. Microcel Installation at the Middle Fork pond reclaim facility, USA.

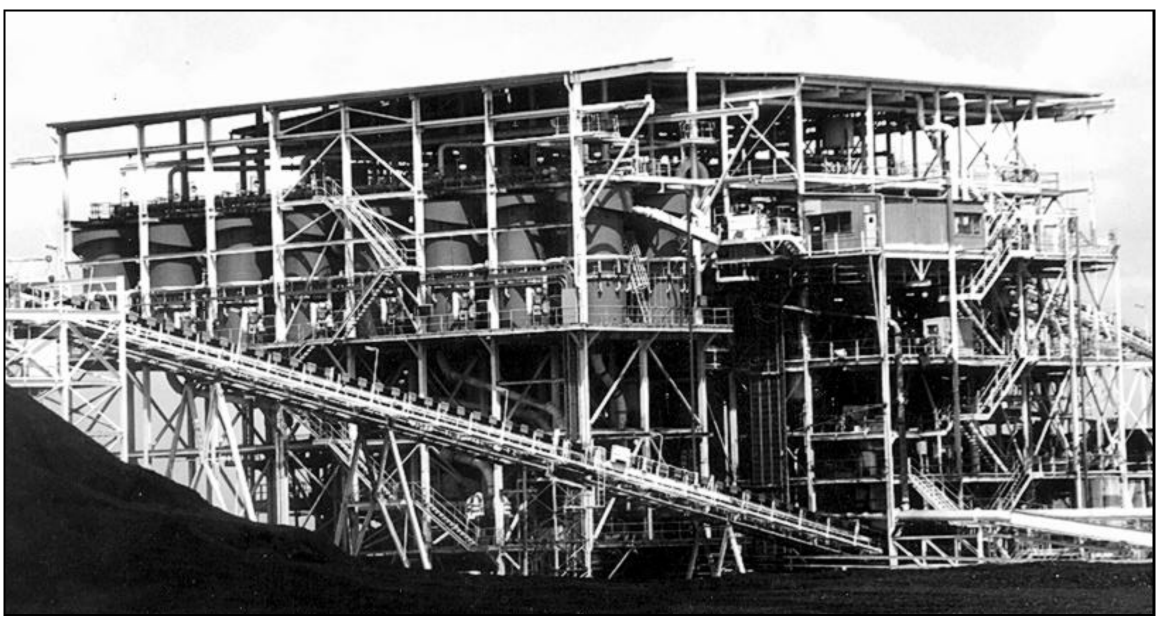

Figure 3. Microcel Installation at Peak Downs preparation plant, Australia.

ADVANCED DEWATERING

Several advanced technologies are now commercially available for the efficient recovery of low-ash products from fine coal streams. Unfortunately, recovery of this material is often difficult to justify due to its high moisture content. In light of this problem, a variety of novel dewatering aids have been under development at Virginia Tech during the past several years. These reagents are capable of substantially improving the performance of most of the mechanical processes currently used for industrial fine-coal dewatering.

Table 3 shows the results of filter-leaf tests conducted in the laboratory using one of the novel dewatering aids developed at the Center for Coal and Minerals Processing. In each experiment, the filter leaf was submersed face-down in a slurry for 15 seconds to form a cake (cake-formation time). The filter leaf was then taken out of the slurry and held in an upright position for 60 seconds to dry the cake (drying cycle time). The vacuum was cut off after the drying cycle time and the cake removed from the filter leaf using a spatula. The experimental data show that the addition of the novel dewatering aid substantially reduced the cake moisture. When no dewatering aid was added, the filter cakes contained 35–42% moisture. After adding 1.5–2.0 kg/t of dewatering aid, the cake moistures were reduced to 25% or less. The moisture reductions ranged from a low of 42% to a high of nearly 60%, which is far superior to those observed with other dewatering aids (Kenny, 1994).

An interesting side effect of using the dewatering aid is that it increased the filter-cake thickness by 2 to 3 times for the same filtration time. Since cake moisture tends to increase with cake thickness (Misra, 1988), it is difficult to compare the moisture data obtained using the filter-leaf technique. Therefore, in order to control the cake thickness, an additional series of dewatering tests was performed using a Buchner filter. The tests used a minus-28 mesh Pittsburgh No. 8 coal sample and 1 kg/t of dewatering aid. In each experiment, approximately 100 ml of slurry was poured into the funnel before applying the vacuum. The results of these tests are summarized in Table 4. In the presence of the dewatering aid, the final cake moisture dropped from 23.1% to 11.7% by decreasing the cake thickness from 18 mm to 5 mm. It was also observed that thicker cakes were generally fractured more easily. Once cake fracture occurred, the vacuum was lost and the drainage process stopped.

Table 5 shows the effects of drying cycle time on the final cake moisture obtained on a minus-100 mesh coal sample using 1.5 kg/ton of the novel dewatering aid. Each test was conducted by adding 100 ml of slurry to the Buchner filter at 14% solids. These conditions provided a constant cake thickness of approximately 5 mm. The initial vacuum pressure was 625 mm Hg, which decreased to 560–585 mm Hg at the end of the test. In the control tests in which no dewatering aid was added, an increase in drying cycle time of up to 10 minutes showed little improvement in moisture reduction (29% vs. 27%). In the presence of the dewatering aid, however, the moisture content decreased substantially with increasing drying cycle time. In fact, the cake moisture was reduced to as little as 3.9% after 10 minutes of drying cycle time. This finding suggests that the dewatering aids developed at Virginia Tech may best be utilized with mechanical dewatering systems (e.g. horizontal belt filters) that can accommodate a long drying cycle time. It should also be noted that use of the dewatering aid decreased the cake formation time by 4–5 times, indicating a drastic increase in filtration rate.

COAL SAMPLE	Sample Description	Without Dewatering Aid	With 1.5 kg/t Dewatering Aid	Moisture Reduction
Middle Fork	-100 M Froth Product	41.9%	23.7%	43.4%
Pittsburgh No. 8	-28 M Filter Feed	41.8%	23.0%	44.0%
Pittsburgh No. 8	-100 M Froth Product	42.0%	24.4%	41.9%
Maple Meadow	-100 M Froth Product	35.8%	14.5%	59.5%

Table 3. Effect of Dewatering Aid Addition on Moisture Content (Filter Leaf Tests)

Cake Thickness (mm)	Without Dewatering Aid	With 1.0 kg/t Dewatering Aid	Moisture Reduction
18	--	23.1%	--
13	32.3%	18.1%	43.9%
10	--	15.6%	--
5	--	11.7%	--

Table 4. Effect of Cake Thickness on the Moisture Content (Buchner Funnel Tests)

Drying Cycle (minutes)	Without Dewatering Aid	With 1.5 kg/t Dewatering Aid	Moisture Reduction
1	29.0%	13.1%	54.8%
5	28.0%	8.8%	68.6%
10	27.1%	3.9%	85.6%

Table 5. Effect of Drying Cycle Time on the Moisture Content (Buchner Filter Tests)

ECONOMIC CONSIDERATIONS

Several advanced processes are now available for the efficient cleaning and dewatering of fine coal. However, the economic feasibility of these technologies cannot be established until their impact on plant-wide performance has been fully assessed and optimized. For example, the overall clean-coal yield (Y) and quality (Q) for a plant consisting of *n* total processes (or circuits) can be calculated as:

$$Y = \sum_{i=1}^{n} S\Sigma Y_i \qquad [1]$$

$$Q = \sum_{i=1}^{n} S\Sigma Y_i Q_i \Big/ \sum_{i=1}^{n} S\Sigma Y_i \qquad [2]$$

in which S_j is the percentage of feed coal reporting to circuit *i*, Y_j is the clean-coal yield from the separator in circuit *i*, and Q_j is the coal quality produced by the separator in circuit *i*. Obviously, a variety of different clean-coal yields and qualities (i.e., ash, moisture, sulfur, etc.) can be obtained by adjusting the operating conditions for each circuit. The optimum operating point is the one that maximizes overall plant yield at a given clean-coal quality. The most commonly used method for identifying the optimum operating point is to sweep through all possible operating conditions for each circuit and to select the combination that provides the highest yield at the desired quality (Peng and Luckie, 1991). However, this hit-or-miss approach is both time consuming and costly. A more attractive method is use of the concept of *constant incremental quality.*
This concept has long been recognized in the coal preparation industry (Abbot, 1981); it states that the clean-coal yield for a multi-circuit operation is maximized when all plant circuits are operated at the same incremental quality. Mathematically, this requires that each circuit be operated such that:

$$Q_x = Q_i + Y_i(\partial Q_i / \partial Y_i) \quad \{\text{for all i circuits}\} \qquad [3]$$

where Q_x is the incremental quality at the selected operating point (i.e., the quality of the last increment recovered when the yield is increased by an infinitesimal amount). For the metallurgical market, this expression suggests that all circuits should be operated at the same dry incremental ash in order to maximize yield. For the utility market, all circuits should be operated at the same incremental inerts (ash plus moisture) to maximize the net heating value delivered to power plants.
The importance of the incremental quality concept is illustrated by the data given in Table 6. This example compares three different ways of operating a preparation plant that serves the steam coal market. In each of the three cases, the operating points for each circuit were set so that the combined plant product contained 10% ash and 8% moisture. In Case I, the plant circuits were not operated under optimum conditions, and as a result, the overall plant produced only 592 tons per hour of clean coal. In Case II, the operating points were optimized such that each of the circuits produced the same incremental inerts of 38%. This was achieved by increasing the incremental ash of the heavy medium bath to 35%, and reducing that of the flotation bank to 13%. In this case, the plant output increased to 604 tons per hour at the same cumulative ash and moisture. The additional tonnage was obtained by replacing relatively pure inert material from the flotation bank with carbonaceous middlings from the heavy media circuit (see Figure 4). Finally, in Case III, an advanced fine-coal-dewatering technique was employed to reduce the moisture of the flotation product to 16%. This reduction allowed the incremental ash in the flotation circuit to be increased to 22% while maintaining the incremental inerts at 38%. This modification allowed the plant output to be further increased to 616 tons per hour.
The difference in annual revenue between Cases I and II amounts to approximately $US3 million at $25 per ton of coal price and 5,000 operating hours per year. This improvement can be realized through the use of advanced fine-coal-cleaning and dewatering technologies that are properly incorporated into a globally optimized plant. This example also illustrates that improvements in fine coal cleaning and dewatering can often benefit the coarse-coal circuit more than the fine-coal circuit.

Case	Circuit	Incremental Ash	Incremental Moisture	Incremental Inerts	Total Plant Yield
I	HM Bath	30%	3%	33%	
	HM Cyclone	31%	7%	38%	592
	Flotation	22%	25%	47%	
II	HM Bath	35%	3%	38%	
	HM Cyclone	31%	7%	38%	604
	Flotation	13%	25%	38%	
III	HM Bath	35%	3%	38%	
	HM Cyclone	31%	7%	38%	616
	Flotation	22%	16%	38%	

Table 6. Effects Of Balancing Incremental Inerts on Total Plant Performance

The data presented in Table 6 illustrate the important role of dewatering in optimizing plant performance. There is, however, a trade-off between the costs and benefits of improved dewatering. For example, consider the case in which the cost of additional dewatering is $1 per ton of fine coal treated (Figure 5a). A producer that sells coal into the utility (steam/thermal) market will normally receive a premium when the heating value is increased through a moisture reduction. If only the premium is considered (lower line in Figure 5a), then a 5% reduction in moisture is needed to recover the additional dewatering cost of $1 per ton of fines. Alternatively, the seller could forego the premium and elect instead to maintain the original heating value of the total clean-coal product by raising the gravities in the coarser coal circuits (upper line in Figure 5a). Because of the increased yield, only a 1% reduction in moisture is needed in this case to recover the $1 per ton dewatering cost. As shown, any moisture reduction beyond 1% would generate considerable additional revenue.

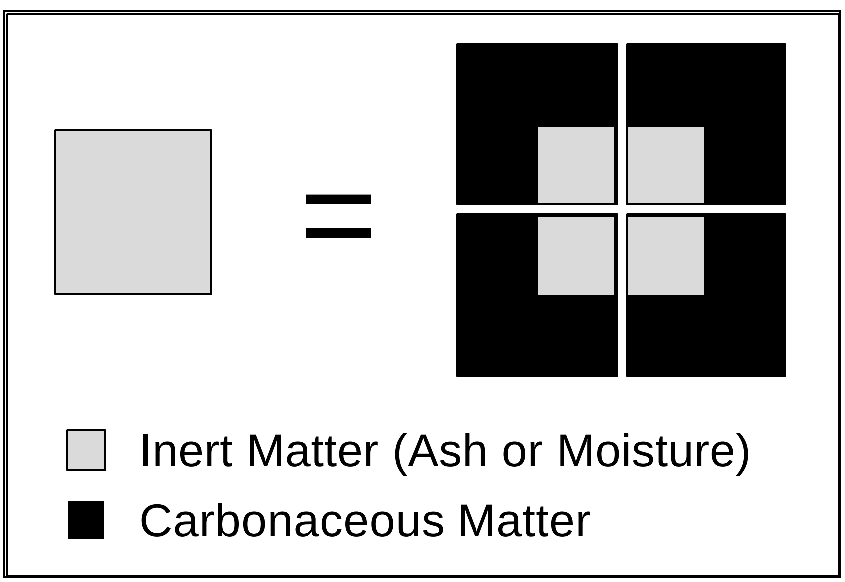

Figure 4. Illustration of the trade-off between inert matter and middlings.

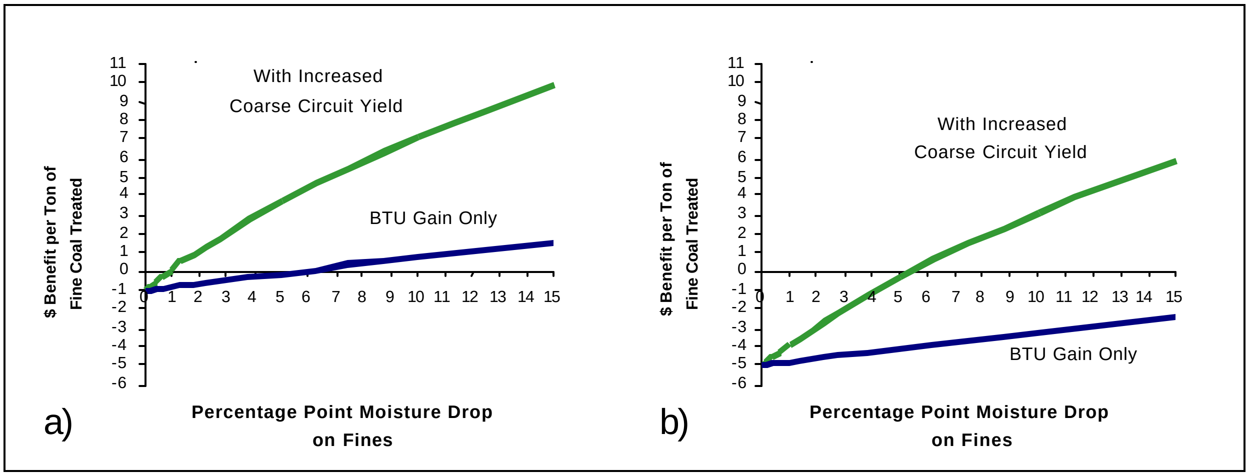

Figure 5. Effects of Moisture Reduction on Fines Dewatering for Costs of (a) $1.00/Ton and (b) $5.00/Ton of Fines Treated *(Base Case: $20/Ton at 12,500 Btu/lb with $0.25/100 BTU Premium/Penalty).*

If the dewatering cost is raised from $1 to $5 per ton of fines treated, then a greater moisture reduction is required to break even (Figure 5b). For this case, a dewatering cost of $5 per ton cannot be recovered if only the premium for higher heating value is considered (lower line in Figure 5b). However, if the seller foregoes the premium and instead raises the gravities in the coarser coal circuits (upper line in Figure 5b), then the additional yield allows a breakeven point to be reached at a moisture reduction of about 5%. In fact, a 10% reduction in the fines moisture (from 30% to 20%) produces a gain of $3.40 per ton of fines treated, even after paying the $5 per ton of dewatering cost. For a 1000 ton/hr plant, this represents $200 per hour (or approximately $US1.2 million annually) of additional revenue.

SUMMARY

Several advanced processes are now available for improving the performance of fine-coal-cleaning and dewatering circuits. Any economic evaluation of these technologies must, however, consider the important interactions between the coarse- and fine-coal circuits on overall plant performance. A reduction in the ash and/or moisture content of the fine-coal product often allows higher cut-points to be employed in the coarser coal circuits without diminishing the quality of the overall plant product. This trade-off generally results in a substantial increase in total plant production. In many cases, the improved profitability can be used to justify improvements to the fine-coal circuit, although the apparent benefit to the fines circuit alone may be relatively small.

REFERENCES

Abbott, J. 1981. "The Optimization of Process Parameters to Maximize the Profitability From a Three-Component Blend." *Proceedings of the First Australian Coal Preparation Conference*, Newcastle, Australia: pp. 87–106.

Blake, I.R., and G. Eldrige. 1996. "The Development of New Microcel Column Flotation Circuit for BHP Australia Coal's Peak Downs Coal Preparation Plant." *Proceedings of the 13th International Coal Preparation Exhibition and Conference*, Lexington, Kentucky, USA: pp. 237–251.

Davis, V.L, F. Stanley, P. Bethell, and G.H. Luttrell. 1994. "Column Flotation at the Middle Fork Preparation Facility," *Coal Preparation – An International Journal*, Vol. 14: pp. 133–145.

Kenny, M.E. 1994. "Coal Dewatering," U.S. Patent No. 5,346,630, September 13, 1994.

Peng, F.F., and P.T. Luckie. 1991. "Process Control, Part 1 - Separation Evaluation," *Coal Preparation, 5th Ed.*, Eds. J. Leonard and B. Hardinge, Society of Mining Engineers, Port City Press, Inc., Baltimore, Maryland, USA: pp. 659-716.

Mishra, S.K. 1998. "Principles of Dewatering," *Proceedings of the Indsutrial Practice of Fine Coal Processing*, R. Klimple and P. Luckie, Eds., Society of Mining Engineers, Inc., Hidden Valley, Somerset, Pennsylvania, USA: pp. 213-221.

Phillips, D.I., R-H. Yoon, G.H. Luttrell, L. Fish, and T.A. Toney. 1997. "Installation of 4-Meter Diameter Microcel™ Flotation Columns at the Lady Dunn Preparation Plant," *Proceedingsof the 14th International Coal Preparation Exhibition and Conference*, Lexington, Kentucky, USA: pp. 115-124.